

MULTIMEDIA



UNIVERSITY

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

## FINAL EXAMINATION

TRIMESTER 2, 2015/2016

### EMF2026 – MICROWAVE DEVICES (MCE)

4 MARCH 2016  
9:00 A.M -11:00 A.M.  
(2 Hours)

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#### INSTRUCTION TO STUDENT

1. This Question paper consists of 8 pages including cover page with 4 Questions only.
2. Attempt all **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please print all your answers in the answer Booklet provided.

**Question 1**

- (a) Figure Q1(a) shows the temperature dependence of carrier concentration for both intrinsic and extrinsic semiconductor. Critically analyse the graph by explaining the shape of the graph for the 3 regions which are region I, region II and region III. The explanation should involve both electrons and holes carrier concentration.

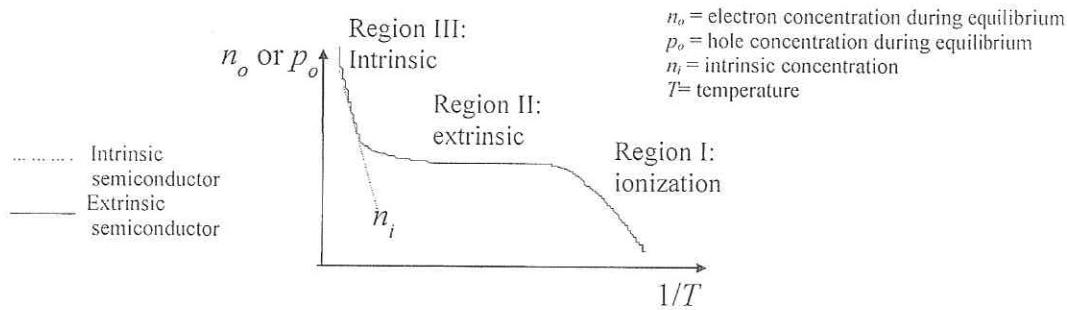


Figure Q1(a)

[7 marks]

- (b) At  $T = 300$  K, the doping concentrations of acceptors,  $N_a$  and doping concentration of donors,  $N_d$  in silicon semiconductor are 0 and  $10^{17}$  cm $^{-3}$  respectively. Given that the mobility of electrons,  $\mu_n = 1350$  cm $^2$ V $^{-1}$ s $^{-1}$ , the mobility of holes,  $\mu_p = 480$  cm $^2$ V $^{-1}$ s $^{-1}$  and the intrinsic concentration,  $n_i = 1.5 \times 10^{10}$  cm $^{-3}$ ,

- (i) find the equilibrium hole concentration,  $p_0$  at 300K. [2 marks]
- (ii) identify the Fermi level,  $E_F$  relative to the intrinsic level,  $E_i$  [2 marks]
- (iii) sketch the resulting energy band diagram based on Qb(ii). [3 marks]

- (c) Calculate the probability that a state in the conduction band is occupied by an electron and calculate the thermal equilibrium electron concentration in silicon at  $T = 300$ K. Assume the Fermi energy is 0.25eV below the conduction band. The value of  $N_c$  for silicon at  $T = 300$ K is  $N_c = 2.8 \times 10^{19}$  cm $^{-3}$ . [5 marks]

- (d) Consider an intrinsic semiconductor with electron concentration,  $n_i$  and hole concentration,  $p_i$ , prove that  $n_i^2 = N_c N_V e^{-E_g/kT}$ . [6 marks]

Continued...

**Question 2**

- (a) A silicon pn-junction at  $T= 300\text{K}$  has the following parameters. Calculate the minority electron diffusion current at the space charge edge.

Acceptor Concentration, $N_a$	$5 \times 10^{16} \text{ cm}^{-3}$
Donor Concentration, $N_d$	$1 \times 10^{16} \text{ cm}^{-3}$
minority carrier electron diffusion coefficient, $D_n$	$15 \text{ cm}^2/\text{s}$
minority carrier hole diffusion coefficient, $D_p$	$10 \text{ cm}^2/\text{s}$
minority carrier electron life time, $\tau_{no}$	$5 \times 10^{-7} \text{ s}$
minority carrier hole life time, $\tau_{po}$	$1 \times 10^{-7} \text{ s}$
Cross -sectional area, $A$	$10^{-3} \text{ cm}^2$
Forward bias voltage, $V_a$	0.625 V

[5 marks]

- (b) Figure Q2(b) shows the energy band diagrams and I-V characteristics of the tunnel diode at both the zero bias (a) and reverse bias (b). Critically analyse the graph by explaining the shape of the graph. The explanation should involve an energy level.

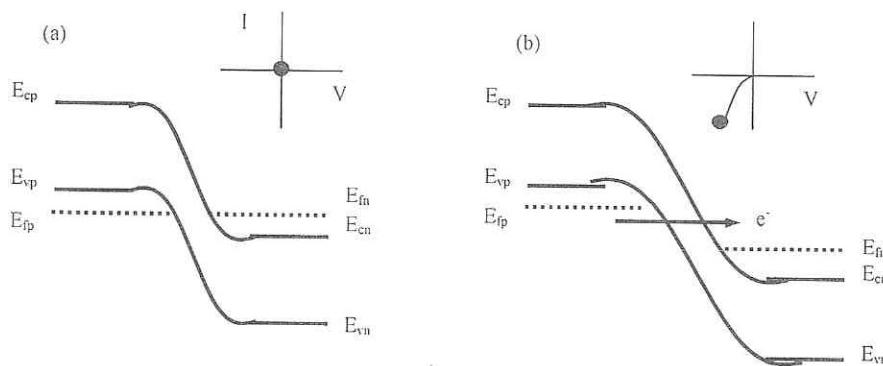


Figure Q2(b)

[4 marks]

Continued...

- (c) By referring to the equivalent circuit as shown in Figure Q2(c), derive an expression for the short-circuit current gain,  $G_i^{SC}$  of a bipolar transistor.

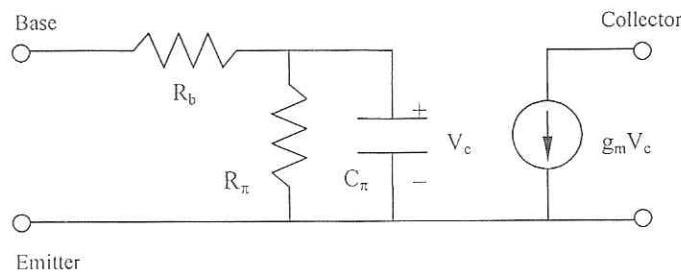


Figure Q2(c)

$$[\text{Hint: } G_i^{SC} = \left| \frac{I_c}{I_b} \right|_{V_{ce}=0} \text{ for a bipolar transistor}]$$

[8 marks]

- (d) The hybrid-pi equivalent model as shown in Figure Q2(d) is commonly used in the normal active mode of the common emitter configuration of microwave bipolar transistor. Simplify the model for operation at low frequency.

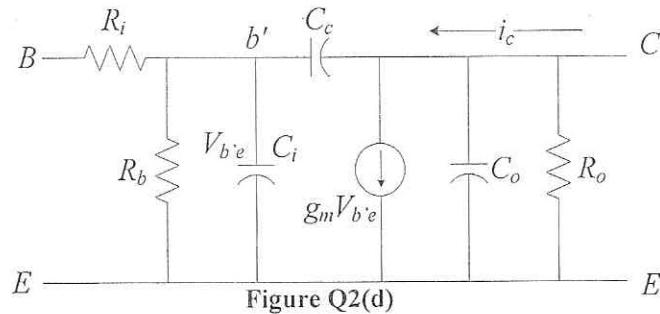


Figure Q2(d)

[4 marks]

- (e) Explain how the opposing effect of drift and diffusion current in a PN junction, leads to zero net junction current at equilibrium.

[4marks]

Continued...

**Question 3**

- (a) From the following Poisson's equation which is used for the voltage in the *n*-channel of Junction Field-Effect Transistors (JFETs) in terms of volume charge density, derive the pinch-off voltage equation,  $V_p$  as a function of doping concentration,  $N_d$  and the channel height,  $a$ .

$$\frac{d^2V}{dy^2} = -\frac{\rho}{\epsilon_s} = -\frac{qN_d}{\epsilon_s}$$

where

$V$  = volume

$\rho$  = volume charge density in coulombs per cubic meter

$q$  = charge in coulombs

$N_d$  = electron concentration in electrons per cubic meter

$\epsilon_s = \epsilon_0 \epsilon_r$  = permittivity of the material in farads per meter

[5 marks]

- (b) An n-channel JFET has the following parameters:

Electron density:	$N_d = 2 \times 10^{17} \text{ cm}^{-3}$
Dielectric constant:	$\epsilon_r = 11$
Channel height:	$a = 0.32 \times 10^{-4} \text{ cm}$
Channel length:	$L = 5 \times 10^{-4} \text{ cm}$
Channel width:	$Z = 40 \times 10^{-4} \text{ cm}$
Electron mobility:	$\mu_n = 680 \text{ cm}^2 / \text{V}\cdot\text{s}$
Drain voltage:	$V_d = 9 \text{ V}$
Gate voltage:	$V_g = -2 \text{ V}$
Built-in voltage:	$\varphi_0 = 0.8 \text{ V}$

Find:

- (i) The pinch-off voltage in volts. [1 marks]
- (ii) The pinch-off current in mA. [1 marks]
- (iii) The drain current in mA. [2 marks]
- (iv) The saturation drain current in mA. [2 marks]

Continued...

- (c) A Silicon  $n-p-n$  transistor has the following parameters:

Collector current,  $I_C = 5\text{mA}$   
 Common-emitter current gain factor,  $h_{fe} = 100$   
 Base width,  $W = 9.8 \times 10^{-5} \text{ cm}$   
 Electron mobility,  $\mu_n = 1600 \text{ cm}^2/\text{V}\cdot\text{s}$

The transistor is operating at 300K. Calculate:

- (i) The mutual conductance,  $g_m$  [1 mark]
- (ii) The input conductance,  $g_b$  [2 marks]
- (iii) The electron diffusion coefficient,  $D_n$  [2 marks]
- (iv) The diffusion capacitance,  $C_{be}$ . [2 marks]

- (d) Figure Q3(d) shows Ridley-Watkins-Hilsum (RWH) scenario where the carriers drift from the left to right of transferred electron devices. Describe the consequences if a constant high voltage is applied across the sample.

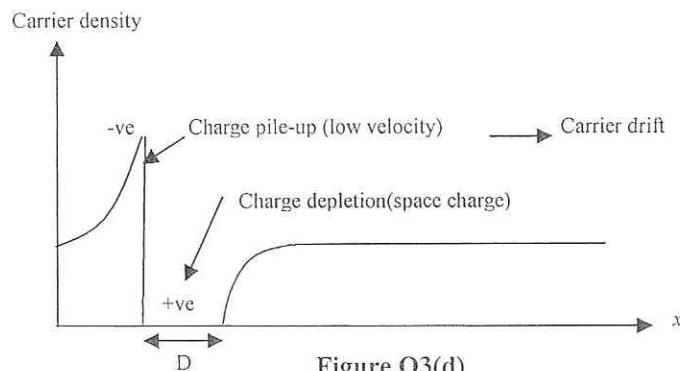


Figure Q3(d)

[4 marks]

- (e) In bipolar junction transistor (BJT), critically provide the reason why  $n-p-n$  structure is preferred for high frequency applications.

[3 marks]

Continued...

**Question 4**

- (a) Figure Q4(a) shows a reflex klystron microwave tubes. Describe the consequences if the buncher gap width,  $d$  is increased.

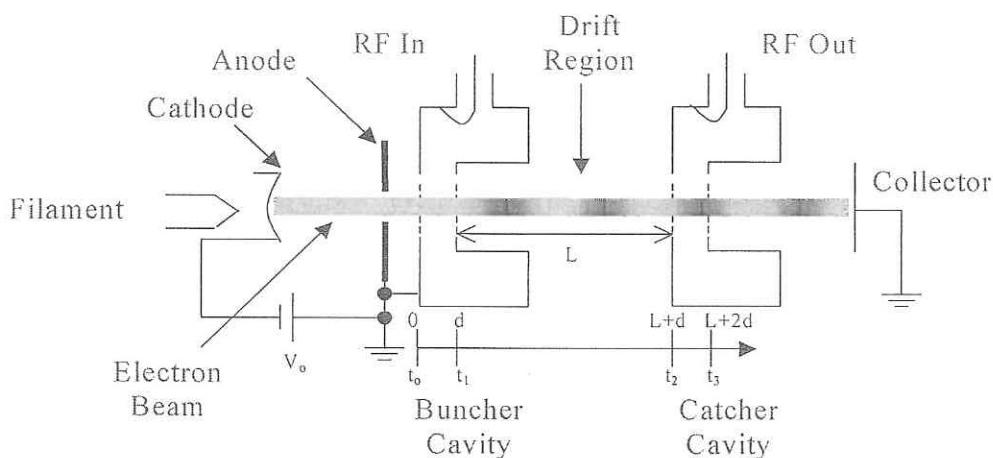


Figure Q4(a)

[3 marks]

- (b) An Impact Ionization Avalanche Transit-Time (IMPATT) diode has a drift length of  $2 \mu\text{m}$ . The diode is operated at dc bias voltage of  $100\text{V}$  and dc current of  $200\text{mA}$ . The efficiency is  $15\%$ . Determine:

- (i) the drift time of the carriers (given the drift velocity is  $10^7\text{cm/s}$ ) . [2 marks]
- (ii) the operating frequency of the diode. [2 marks]
- (iii) the output power. [2 marks]

Continued...

- (c) A two-cavity klystron amplifier is tuned at 3 GHz. The drift space length is 2 cm and beam current of 25 mA. The catcher voltage is 0.3 times the beam voltage. Assume the beam coupling coefficient  $\beta=1$ , bunching parameter  $X = 1.841$ , and  $J_1(X) = 0.582$ . For mode number  $N = 5 \frac{1}{4}$ , compute the following.

- (i) dc beam velocity. [3 marks]
- (ii) beam voltage. [2 marks]
- (iii) power output. [2 marks]
- (iv) efficiency. [2 marks]

- (d) Figure Q4(d) shows the drift velocity versus electric field intensity for carriers in Avalanche Transit Time devices made of Gallium Arsenide (GaAs) and Silicon (Si). Analyze the graph by determining the effect of electric field and significant differences between the 2 types.

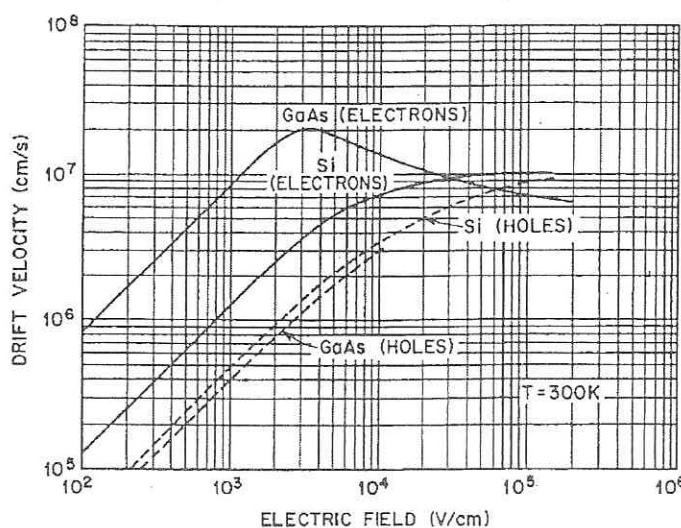


Figure Q4(d)

[4 marks]

- (e) In an impact ionization avalanche transit-time (IMPATT), critically provide reason it is generally not used for local oscillators in microwave and millimeter-wave receivers.

[3 marks]

End of Paper